# The Geospace Plan
# for
# Living With a Star

## Summary

The Geospace Plan for Living With a Star (LWS) is based on the overarching objective of the LWS initiative to understand the effects of solar variability on those geospace phenomena that most affect life and society. It defines which phenomena occurring in geospace apply most significantly to the LWS goals (radiation exposure, communications and navigation errors and outages, energy forcing of the upper atmosphere), and uses the LWS priority ranked goals to prioritize where studies are essential to gain an understanding and characterization of the defined phenomena. The plan describes an approach where the characterization is accomplished with a core set of measurements over solar cycle time scales and the understanding is achieved with a more complete set of measurements over a shorter period. Because the effects in geospace relevant to LWS occur over a large region, the Geospace Plan invokes a distributed approach to understand the associated phenomena. The plan identifies two regions of geospace where these phenomena primarily occur, specifically the Earth's radiation environment and the ionosphere/thermosphere region.

The Geospace Plan has four components:

- **Geospace Missions Network**: This the primary component of the Geospace plan. The goal of the Geospace Missions Network is to provide measurements required to meet the LWS objective of understanding the response of geospace to solar variability and its impact on society. It consists of several dedicated NASA spacecraft located in key geospace regions. Possible scenarios might include in-situ measurements with multiple spacecraft in geo-transfer orbits, spacecraft in different inclination low-Earth orbits, and a high-inclination elliptical remote sensing spacecraft. To achieve the LWS goals the Geospace Missions Network is intended to fly concurrently with other LWS missions, in particular the SDO, so that the response of geospace is characterized as a function of well-specified variable solar energy inputs.
- **Missions of Opportunity**: These are those flight opportunities where LWS Geospace might provide instrumentation and or resources to an existing space-based platform in order to acquire needed measurements for the characterization and understanding of geospace; e.g. C/NOFS flight of CINDI under the Explorer program.
- **Leveraged Programs**: These are current or future programs outside of LWS that provide geospace products that are relevant to meeting the LWS objectives. These products might include data sets, investigation results, models and model results; e.g. DMSP, POES, GOES, GPS measurements, ground based programs.
- **Instrument Development Program**: This is a mechanism to incorporate recent technological advances for the design and development of small, efficient and low-resource flight instrumentation in the Geospace Missions Network and Missions of Opportunity. It is intended to begin in FY02.

The Geospace Plan includes the immediate formation of a **Geospace Mission Definition Team** (GMDT) that responds to NASA Headquarters LWS. The GMDT responsibilities include defining/finalizing the Geospace Missions Network, recommending Missions of Opportunity, identifying Leveraged Programs products and recommending targeted instrumental development areas. The GMDT will use as a basis for its recommendations the LWS Science Architecture Team's (SAT) science and

measurement priorities for geospace. The GMDT will work closely with the SAT and LWS Program Office.

## Objective and Goals

The overarching objective of the LWS initiative is to understand and characterize the effect of solar variability on those geospace phenomena that most affect life and society. The LWS priority ranked goals are to:

1. Determine solar influences on climate change
2. Characterize the space environmental
2. Enable Nowcasting of space environment
3. Enable Prediction of space environment, especially of solar proton events, and geomagnetic storms

The objective of the Geospace Plan is to define those phenomena occurring in geospace that apply most significantly to the LWS goals. Due to resource constraints, priority is given to those phenomena that are the least understood and have the largest impact on society. A preliminary analysis of the various important geospace phenomena indicate that the most significant phenomena occur in the radiation belts and the thermosphere/ionosphere.

Understanding and characterizing the key plasma parameters in these regions is important for developing physics-based and empirical models for specifications and for diagnosing and predicting a wide variety of space weather effects, including global climate change, satellite anomalies, satellite drag, disruptions of communication, navigation, and radar systems, and astronaut radiation safety.

## Requirements and Priorities

### *Earth's Radiation Belts*

Over the decades of space plasma research, much has been learned about the typical configurations of the Earth's radiation belts and how they generally change over the Sun's 11-year cycle. Examples of the strong variability of the belts over various time scales have been observed. Some of the processes that energize, transport and cause loses of radiation belt particles are now understood. However, many of the links in the chain of processes that populate, energize, transport and cause losses of the radiation belt particles and which processes dominate under various geophysical conditions are not understood. Thus the ability does not exist to specify the radiation belt intensities, distributions in distance and latitude, and time variability that result from changes in external and internal conditions, including:

- solar wind parameters with the resultant
  - coupling of energy into the magnetosphere
  - distortions of the magnetosphere
  - geoelectric field
- external and internal source strengths
- internal seed populations
- electromagnetic wave activity

Consequently, the ability to extrapolate to radiation belt parameters that will result from extremes in external and internal conditions does not exist. These parameters are needed for predictive and specification models.

In addition, the role that the radiation belts play in the highly time-varying magnetosphere-ionosphere current system, which deposits sporadically large amounts of energy into the atmosphere, is largely speculative. Understandings of such thermosphere-ionosphere effects depend on an understanding of magnetosphere-ionosphere coupling.

The objective of the radiation belt investigation is to enable understanding of the sources, transport and losses of radiation belt particles. Since the belt particles consist of a variety of species over wide energy ranges, an evaluation must be performed to identify those particles and energy ranges that are most pertinent to LWS goals. A preliminary assessment gives the following priorities:

1. Outer belt electrons: 1 keV to 10 MeV

These are a highly variable population of particles with the least amount of understanding: origin (seed population), transport and loses; and they produce the most significant impacts on space systems: satellite anomalies, deep dielectic charging, dose, spacecraft charging and EVA crew exposure. An understanding and characterization of these particles will result in the predictive and specification models needed to optimize spacecraft and systems designs. Special emphasis is directed toward this penetrating radiation as it is related to geomagnetic storms.

2. Slot region protons and electrons: 0.01 to 50 MeV protons, 0.01 to 20 MeV electrons.

These particles fill the region between the inner and outer belts on occasion in response to unusual solar wind conditions. Sources, energization mechanism(s), losses and frequency of occurrence are unknowns. Their very high energies make them of interest to the user community for reasons similar to the outer belt electrons. Because of their sporadic existence, an understanding of these particles does not rate as high a priority as the outer belt electrons.

3. Ring current ions: 10 to 300.

This topic is of special interest to the science community because the ring current enhancement is the primary current for producing the world-wide magnetic disturbances of magnetic storms. It may be the source for storm-time Region 1 field-aligned currents, which couple large amounts of energy into the atmosphere. Since their effects on space systems (degradation of solar cells and surface coatings of spacecraft), is not as severe as the priority 1 and 2 particles, an overall evaluation gives a lower priority.

4. Inner belt protons and South Atlantic Anomaly: 1 – 500 MeV

These high-energy particles are the most understood radiation belt particles, so have lesser interest by the scientific community. Because of their high energies they produce a variety of effects on spacecraft and biological systems, so have high priority among the user community.

### *Ionosphere/Thermosphere*

Although the thermosphere and ionosphere regions of the space environment are known to be highly variable, cause–effect relationships have for the most part been examined only intermittently and in isolation, i.e. with limited context, spatial and temporal coverage. Of special interest to LWS, for reasons outlined below, are the main contributions to the heating and ionization of this region; solar EUV, auroral precipitation, and the ionospheric portion of the geospace electric current system (Joule heating). During the past few decades, statistical and physical models have been developed to describe the thermosphere and ionosphere regimes. Both characterizations of significant events as well as empirical models are used to aid systems design and in space weather operations, such as the specification of spacecraft drag. However the models have not been validated due to the lack of an adequate observational database. As a result, the LWS relevant empirical ionosphere/thermosphere models currently in use are outdated and often contain inadequate information concerning various drivers and neutral motions. In order to understand this region both empirically and predictively, these primary drivers must be observed concurrently with the geospace measurements.

The objective of the ionosphere/thermosphere investigation is an improved understanding and characterization of the phenomena in this region that most affect space weather and the space environment, astronauts and assets in space, on time scales ranging from solar storms (days) to the solar cycle (decades). Thus scientific understanding of events with significant space weather impacts are targeted as highest priority. For our purposes here, we consider atmospheric drag and disruptions of radio-based communication, navigation, and radar systems as the two most critical issues for which Living with a Star can have the most impact.

In addition to observations made in support of understanding space weather and as a link to Earth climate programs, measurements of composition, temperature, winds and waves in the lower thermosphere and middle atmosphere may be important. Needed are measurements of odd-nitrogen and odd-hydrogen species that are thought to play a role in coupling of the upper and lower atmosphere, through which solar variations may affect ozone and indirectly climate.

1. Satellite Drag

Satellites with perigees below about 500 km experience drag forces that alter the satellite orbit and eventually cause re-entry. Such drag forces may also cause spacecraft attitude perturbations that can misalign solar panel and telemetry antenna orientations in deleterious ways. In other cases, they might necessitate that a long-lived satellite, such as the International Space Station, undergo expensive “re-boosts” and/or re-orientations to maintain a healthy orbit. The accuracy of drag predictions will determine the fuel load necessary to safely de-orbit a satellite at the end of its life. Rapid orbit perturbations can cause the loss of a large number of objects being tracked for safety purposes.

Although the physics of the drag problem is well understood, our characterization of the state of the upper atmosphere, as well as our ability to predict and forecast its variations, remain inadequate. It is well known that the upper atmosphere density varies with solar and geomagnetic activity, however, the specification models used today to predict that density are based on averages of limited measurements without accurate concurrent knowledge of the drivers.

Progress in understanding and characterizing the spatial and temporal behavior of the thermosphere, responsible for orbital drag, requires global measurements of its primary state variables: neutral density and composition, neutral temperature, neutral winds. In addition, it is essential to assess the drivers of thermospheric energetics and dynamics, including: solar FUV, EUV and X-ray, ionospheric properties, electric field, magnetic fields, currents, energetic particles and auroral precipitation.

2. Navigation/Communication/Radar Disruptions

The earth’s ionosphere is an ionized medium that has significant effects on radio wave propagation in space. Both the ambient ionospheric plasma density and irregularities in this density can severely impact this propagation. Understanding and characterizing the spatial and temporal behavior of the plasma density and irregularities are needed for mitigation and diagnosis of these disruptions.

Despite decades of ionospheric research, models of the earth’s ionospheric density are still inadequate. The density itself is driven by Solar EUV, x-rays, auroral precipitation, electric fields, and interaction with neutral densities and winds, and the resulting predicted profile may often be in serious error. As the ionospheric density also affects satellite potentials and a variety of spacecraft systems, improved knowledge of the distribution and behavior of this fundamental space parameter is inherent to many of the goals of the Living With a Star Initiative.

Progress in understanding and characterizing the spatial and temporal behavior of the ionosphere, responsible for disrupting radio wave propagation, requires global measurements of its primary state variables: plasma density and composition, plasma temperatures, plasma drift. In addition, it is essential to assess the drivers of ionospheric energetics and dynamics, including: solar EUV and X-ray, electric and magnetic fields, precipitating particles, neutral density, composition and winds.

### *Human Exposure to Radiation*

The polar cap is generally open to radiation from the heliosphere. Most of the time this radiation is benign, composed of low energy electrons and ions that have little impact on LWS objectives. However, for periods following solar energetic particle events, large fluxes of very penetrating protons reach low altitudes and pose dangers to extra-vehicular activities and high altitude human flight. The latitudinal extent of the polar cap is dependent upon the deformation of the Earth's magnetic field, or in practical terms, the ability to predict the latitudinal cut-offs of very energetic charged particles. Thus predicting the exposure of human activities passing through the polar cap depends upon the ability to model the magnetosphere during highly disturbed periods. The energy domain of these particles extends as high as inner belt proton fluxes.

The South Atlantic Anomaly has high-energy particle precipitation. Because of their high energies they produce a variety of effects on spacecraft and biological systems.

The primary objective of human exposure to radiation investigations related to LWS goals is to develop the capability to predict the solar activity dependent cut-offs of energetic particle precipitation and the levels of intensity.

## Approach

The approach of the Geospace Plan identifies four components: the Geospace Missions Network, Missions of Opportunity, Leveraged Programs and an Instrument Development Plan. The details of this approach will largely be defined by a Geospace Mission Definition Team.

#### *Geospace Mission Definition Team*

A Geospace Mission Definition Team (GMDT) will be formed with responsibilities to define the Geospace Missions Network, recommend Missions of Opportunity, identify Leveraged Programs products and recommend targeted instrumental development areas. The GMDT will use as a basis of its recommendations the LWS Science Architecture Team's science and measurement priorities for geospace. Its membership will be cross disciplinary comprised of people representative of the LWS community, including users of space weather data and scientists from geospace and solar/heliospheric communities. The LWS SAT will be represented on the GMDT. The GMDT must be committed to working closely with the LWS SAT, LWS Project, NASA/HQ LWS Program and the LWS community in order to achieve the objectives of the Geospace Plan.

#### *The Geospace Missions Network*

The Geospace Missions Network will be comprised of several small NASA missions that will be flown concurrently in key regions of geospace. The details of how the missions will accomplish the objectives of the Geospace Plan will be developed by the GMDT.

The approach to be defined by the GMDT should include consideration of a number of important factors. To gain an understanding of the radiation belts, plasma measurement requirements include coverage of phase space distributions of the priority radiation belt particles, and electric and magnetic fields over the frequency domains of interest to these particles. Simultaneous measurements at different radial distances and local times are important requirements for modeling acceleration and transport of the particles. The bulk of the radiation belt population is best measured near the geomagnetic equator where all trapped particles pass. However, precipitating particles that affect the ionosphere and thermosphere are best observed at low altitude where the loss cone is broad.

Synergy between radiation belt missions and solar terrestrial probes, Explorer missions and the Solar Dynamics Observatory (SDO) will play a critical role in the ability to gain an understanding of the radiation belts. The data collected and the better understanding acquired during the analysis phase must lead to the development of empirical and three dimensional dynamic science-driven radiation belt models with short scale (magnetic storm) to long scale (solar cycle) temporal characteristics.

To gain an understanding and develop a characterization of the ionospheric and thermospheric phenomena of priority to LWS, measurements of the neutral and plasma densities, compositions, and temperatures, along with precipitating particles and electric and magnetic fields over the frequency domains of interest in the region are required. At the same time, inputs to the system from both the heliosphere and magnetosphere must be available. The data acquired must result in scientific understanding of both specific events and longer-term fluctuations. These data will enable nowcasting/forecasting of ionosphere/thermosphere state parameters and dynamics by providing needed input and constraints to initialize and drive physics-based theoretical models. Again, the synergy between ionosphere/thermosphere missions and missions from a number of related programs will play a critical role in achieving the LWS goals (e.g. solar-terrestrial probes, radiation belt missions, DOD and DOE missions, and SDO).

Penetrating radiation is a primary parameter for LWS interests in the area of Human Exposure to Radiation. High-energy particle detectors on LWS missions and/or Missions of Opportunity should be used to acquire the needed data.

The needed measurements may not require state-of-art instruments or the most complete suite of instrumentation possible, an analysis that the GMDT must also perform.

The details of how the missions will accomplish the objectives of the Geospace Plan will be finalized by the GMDT. Prioritization of the measurements will be based on the SAT recommendations.

One possible mission scenario might include the following (assuming limited launch costs, SMEX class spacecraft):

- 2 spacecraft in geosynchronous-transfer orbit (E&M fields, plasma, particles)
- 2 spacecraft in low-earth orbit (2 inclinations) (E&M fields, plasma, particles, neutrals)
- 1 spacecraft in high latitude-elliptical orbit (remote sensing FUV & ENA)
- Missions of Opportunity in geosynchronous orbit (E&M fields, plasma, particles, remote sensing)
- Leveraged Programs (e.g. TIMED, CNOFS, DMSP, GOES, NPOESS, etc.)

Some of these satellites may be launched on rides shared with other programs, though the Geospace Missions Network will not rely exclusively this access to space for mission success. However, attempts to secure shared rides are part of the plan, recognizing that the more such rides are realized, the more resources become available for satellites.

***Missions of Opportunity***

Opportunities may exist or become available that provide for space on a space-borne platform or the enhancement of planned instrumentation that would be consistent with the objectives of the Geospace Plan. These opportunities are critical for characterizing the extremes of variability of trapped particle fluxes, atmospheric densities and ionospheric variability, and entry of solar protons into the polar cap during various types of solar and magnetic activity and over most of a solar cycle, outside of the epoch of the Geospace Missions Network. These measurements would require considerably less fully instrumented packages than Geospace Missions Network satellites. Special consideration for long term characterizations of the radiation belts, energy deposition into the atmosphere and global variability of thermospheric parameters should be given to various imaging techniques.

The obvious synergy with the radiation tolerance goals of the LWS Space Environment Test (SET) Beds indicate that SET is a prime candidate for one or more Missions of Opportunity for Geospace. It is recognized that there are inherent difficulties associated with planning for such opportunities. However, in order to maximize the effectiveness of the Geospace Plan, these opportunities cannot be discarded and will be examined on a case-by-case basis. The GMDT will provide recommendations for Missions of Opportunity.

***Leveraged Programs***

Several other programs are either currently or will be in operation over the next decade that are relevant to LWS and in particular to Geospace. These include space missions, ground-based programs, programs supporting model development and associated results. The goal is to integrate these data and results from other sources into the LWS observations in order to achieve the system understanding and characterization. The GMDT will identify programs within and outside of NASA whose products will contribute to achieving the goals of LWS.

As one example, two planned missions will address the problem of plasma irregularities. One is the Air Force C/NOFS satellite, which will study equatorial Spread-F, while NASA's GEC mission, will address the high latitude polar cap irregularities.

***Instrument Development Program***

The objective of the Geospace Instrument Development Program (GIDP) is to provide for the development of resource-efficient instruments that will enable the Geospace missions to achieve maximum return of investment. The GIDP will use the existing Planetary Instrument Development Program as a pattern to the extent that is reasonable. This program will begin in FY02 and will target 2-3 year proposals that are consistent to the instrumentation needed for the Geospace Mission Network and Missions of Opportunity. The GMDT will provide recommendations for targeted instrumental development areas.

## Conclusion

The Geospace Plan for LWS is composed of 4 components that together provide for the most effective way to achieve the LWS goals for Geospace. It is a plan that engages the community, encourages partnerships and collaborations, is flexible and extends through the first decade of the LWS Program. To achieve the LWS goals the Geospace Missions Network is intended to fly concurrently with other LWS missions, in particular the SDO, so that the response of geospace is characterized as a function of well-specified variable solar energy inputs. In this way the space environment that extends from the Sun to the Earth, and its societal impacts, can be properly understood as a whole system.